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Determining potential locations for biomass valorization using a macro screening approach

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ABSTRACT

European policy states that by 2020 at least 20% of final energy consumption should come from renewable energy sources. Biomass as a renewable energy source cannot be disregarded in order to attain this target. In this study a macro screening approach is developed to determine potential locations for biomass valorization in a specified region. The approach consists of five steps: (1) criteria determination, (2) data gathering, (3) weight assignment, (4) final score, (5) spatial representation. The resulting outcome provides a first well balanced scan of the possibilities for energy production using regional biomass. This way policy makers and investors can be supported and motivated to study the possibilities of building energy production plants at specific locations in more detail, which can be described as a 'micro-screening'. In our case study the approach is applied to determine the potentially interesting locations to establish a biomass project. The region has been limited to the forty-four communities in the province of Limburg (Belgium). The macro screening approach has shown to be very effective since the amount of interesting locations has been reduced drastically.

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1. Introduction

European policy states that by 2020 at least 20% of final energy consumption should emanate from renewable sources. Biomass cannot be disregarded in order to attain this target. At the same time biomass will enhance energy security in the EU [1].

Biomass is currently the most abundant and versatile form of renewable energy in the world [2]. Many studies have been performed to investigate biomass potentials at different levels and using multiple methodologies [1,3–7]. Estimations vary between zero and satisfying the world energy demand multiple times [5]. The potential has been subject to contradiction. Firstly, biomass has many more applications than renewable energy only [2,6,7]. For example, using some biomass types for energy or biofuels may compete with the demand for food and feed. Secondly, some authors recommend the import of low cost biomass from outside the EU [8], although this may cause external costs to society due to long transportation distances.

Since biomass is often too bulky to ship over long distances, it should either be pretreated, or more regional

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applications of biomass should be preferred. In addition, minimizing the transport distance could decrease the production of greenhouse gases. The focus on regionally available biomass sources will also reduce the production cost of bio-energy [9]. Allen *et al.* [10] estimated 20–50% of the biomass delivered cost to be coming from transport and handling. Moreover, a regional approach will reduce the uncertainty concerning the biomass potential. Local circumstances can be taken into account, leading to more accurate estimations [11]. By simultaneously using various types of biomass the energy production plant's long-term supply is ensured and potential problems (e.g. seasonal fluctuations, price rise) can be circumvented [12]. Furthermore, economies of scale can be achieved by using multi-biomass energy flows. Nilsson & Hansson [13] indicate a cost reduction of 15–20% using two biomass types instead of one. A sound screening approach to determine optimal localization within a minimum time span for regional multi-biomass valorization is needed.

As indicated by Ma *et al.* [14] locating optimal sites for biomass conversion is a complex task involving many environmental, economic, and social constraints and factors. Furthermore, biomass projects are typically site-specific. Therefore, especially when a large area is considered, it is impractical and pointless to optimize for every possible plant location [15]. Calvert *et al.* [16] conclude there is a lack of baseline information at the agenda-setting stage of public and private energy planning which prevents decision makers from taking bio-energy seriously. Robust information is the lubricant for decision making and is the only way to minimize the unintended consequences of those decisions. Ayoub *et al.* [17] argue that many decision support systems (DSS) are constructed for one type of biomass from a specific point of view (economical, environmental or social). However, understanding the interdependency of these factors is essential because the failure of one factor can lead to the failure of the whole project [18]. A method is needed that handles multiple biomass stakeholders' objectives and involves different types of biomass. Since many stakeholders of biomass projects have diverse and often conflicting perspectives, a barrier may arise which impedes fluent communication. Therefore, an open, transparent and participatory process is needed to find a balance between the different stakeholders and to move towards a more objective method [19]. The transparency of the method is important since it builds confidence in the decision making process where multiple stakeholders with conflicting views are involved [20]. Zubaryeva *et al.* [21] argue that the participation of different stakeholders during the planning phase is fundamental for the smooth territorial integration of biomass projects at the local scale. Besides the complexity of biomass systems, another problem is the limited availability of data [19]. Information can be generated using interviews and questionnaires with local stakeholders, but this process is time and cost consuming and hence, not feasible in a large area.

The use of multi-criteria decision analysis (MCDA) is widely spread in energy planning [22]. De Lange *et al.* [23] conclude that the use of MCDA facilitates the participation process and that it has an important role in the successful uptake of policy and management strategies and long-term planning. Literature reviews by Pohekar & Ramachandran [24] and Wang *et al.* [25] showed that the analytical hierarchy process (AHP) is the most applied technique, followed by outranking techniques. Moreover, geographical information systems (GIS) are often used in the context of bio-energy [26,27], especially for the site selection of a biomass power plant [14,28,29] and the evaluation of biomass supply [27,30–33]. Many authors have recognized that the combination of GIS and MCDA provides a powerful tool for site selection [14,34,35]. GIS offers a spatial representation of the results whereas MCDA takes economic, social as well as environmental aspects of the problem into account [36].

This paper will shed its light on how to determine potential locations for biomass valorization on a regional scale within a minimum time span. Therefore, a combined MCDA-GIS approach has been developed, described as a 'macro screening'. The screening approach considers different relevant criteria to determine potential locations for biomass valorization in a specified region. In fact, a macro screening provides a first well balanced scan of the possibilities for energy production using regional biomass. The macro screening answers to most of the above mentioned concerns and is therefore considered an interesting method. It allows for policy makers and investors to be supported and motivated to study the possibilities of building energy production plants at specific locations in more detail. The approach will be discussed in detail in section two. In the third section it will be applied to a case study. In the fourth and final section the method's strengths and weaknesses will be discussed and our conclusions summarized.

2. Methodology

The goal of the macro screening is to identify locations that are deemed 'highly interesting' for energy production based on readily available information. Often, the determination of a location is based on a single criterion (e.g. potential heat consumers or available amount of a specific type of biomass). Our method is more proactive and gives an answer to policy makers and investors' demand for a more substantiated evaluation on site selection. The need for a fast and efficient way to explore the market has also been recognized in other domains such as landfill mining [37,38] and sustainable agriculture [39]. Up to now this need has not been translated into an adequate methodology for biomass valorization site selection. This paper aims at filling this gap. A complementary approach is needed to perform a final site selection. While the macro screening significantly reduces the number of locations, the 'micro-screening' subjects the remaining locations to a more detailed exploration and determines the optimal one. However, the micro-screening method falls beyond the scope of this paper.

Macro screening focuses on minimizing the required time to perform site selection. It is not feasible to investigate every alternative in detail within a reasonable time frame. The macro screening consists of five steps. Firstly, all criteria on which an alternative can be rated, must be identified since site selection can be considered as a multi-criteria decision making problem. Then, data must be gathered for each criterion agreed upon to be included in the analysis. These data provide a score for each alternative. Considering not every criterion is equally important, in a third step a weight must also be assigned to each criterion. Fourthly, final scores are found for every alternative by summing the multiplications of the scores and the weights per criterion. Finally, a spatial representation of the weighted criteria can be obtained by combining the MCDA method with GIS. This stepwise approach is represented in Fig. 1. Note that these steps can be performed in parallel and that some steps may be repeated as a result of learning during the process. The macro screening is performed specifically for biomass site selection and therefore, takes into account the specificities typical for biomass.

2.1. *Criteria determination*

To consistently assess whether a certain area is eligible for planting an installation, decision making criteria must be chosen. It is highly recommended to organize an expert panel discussion to identify a set of criteria. Experts should have different backgrounds given the value of their differing points of view. Consequently, a maximal amount of information can be taken into account. By allowing experts to participate early on in the process, the probability of acceptance of the final decision is enhanced. The set of main criteria and their subcriteria is, however, only the starting point. During the process criteria can be added, deleted, substituted and merged in a follow-up discussion or feedback moment. At any time during the first two steps a criterion may respectively turn out to be useful, impractical, misleading or having a similar contribution as another criterion. The criteria can be quantitative as well as qualitative. A MCDA method allows for the processing of both kinds of data [40]. The criteria have to meet four requirements to be used in a macro screening: (1) comprehensibility, (2) having predictive value, (3) being operational (*i.e.* measurable and meaningful), (4) being quantifiable based on readily available information. It is not possible to define the exact number of criteria necessary to adequately evaluate the alternatives since this is highly situation dependent. On the one hand, too little criteria lead to an incomplete answer to the problem. On the other hand, too many criteria make the processing too difficult. A formal way of knowing whether the set of criteria is sufficiently complete, other than relying on experience and intuition, does not exist. Therefore, the involvement of a significant number of experts from various backgrounds is crucial in this setting. The only rule that must be kept in mind is that the number of sublevels and the number of criteria per sublevel must be balanced for every main criterion (see *infra*, Section 2.3).

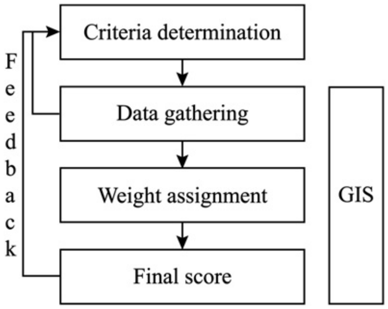

Fig. 1 – Macro screening approach.

Typical for multi-dimensional biomass projects is the diversity of input streams and techniques. In addition, biomass projects have an influence on many factors (*i.e.* economic, social, environmental). Therefore, it is recommended to consult local biomass experts with various fields of expertise as they are most familiar with the working situation. However, they are often only experienced with one sort of biomass and its accompanying conversion process. Hence, it is advised to invite local experts with different specific knowledge. The following list of experts is recommended to be involved when performing a macro screening for biomass projects: (1) expert(s) from the industry (e.g. wood processing, food, brewery); (2) expert(s) in forest management; (3) representative(s) of agriculture; (4) member(s) of local government; (5) expert(s) in municipal waste processing; (6) expert(s) in nature conservation and maintenance; (7) expert(s) from knowledge institutions; (8) expert(s) from similar projects; (9) private investors. The list is cross-checked with recommendations from literature [23,37,41–44].

A set of four main criteria, recommended by the experts, was agreed upon to be sufficiently covering all important elements influencing the primary, rough location decision for a biomass project. Furthermore, it is assumed that they can answer to the need for a more uniform set of criteria for biomass projects [18,19,45]. The four main level criteria are: ‘input’, ‘output’, ‘installation’ and ‘society’. Input should contain the different theoretical biomass potentials. The criterion output should be composed of present heat consumers. The criterion installation should hold the biomass installations that are currently installed or planned. Finally the criterion society should measure the willingness of communities to accept the project in their area. It is interesting to take the willingness of communities into account early in the process since other cases have shown that public opposition is common [46,47]. Some authors even claim that the leap towards broader biomass utilization for bio-energy is more psychological than technological [48]. The chosen subcriteria can differ depending on the region since a biomass project is typically site-specific and, hence, requires a unique screening [14]. A list of advised subcriteria per main level is presented in the case study.

2.2. *Data gathering*

The macro screening data is gathered by desk research. The data sources used must be readily available, e.g. databases, articles or public data available from research institutes, regional/national/European authorities, internet, *etc.* The researcher must always ask oneself whether the time needed to collect the information outweighs the additional value it can provide. Since this entails many trade-offs, the found data will never give a complete representation of reality. However, this is not a necessity, the information must give an acceptable indication of reality. Yet, the more information gathered, the more likely the optimal location will be among the identified locations. After an initial set of criteria is determined, data gathering is performed in parallel to step 1.

The collected data provide a value for each criterion for every alternative. The different units, in which the criteria may be expressed, do not pose a mathematical problem because normalization can be performed. By using, for example, a linear scale transformation, a value x_{ij} will be transformed into a score r_{ij} between zero and one by using equation (1) for criteria positively influencing the goal and equation (2) for criteria negatively influencing the goal. The outcome is more favorable as r_{ij} approaches one [49,50].

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{1}$$

$$r_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{2}$$

2.3. Weight assignment

Weights have to be assigned to indicate a criterion's importance and should preferably be performed by experts (see *supra*, Section 2.1). Methods to assign weights are sensitive to changes in the number of criteria, the decision maker must therefore be certain that the set of criteria is final before going over to the weight assignment. The most popular MCDA methods are analytical hierarchy process (AHP) and outranking methods [24,25].

The decision making criteria are split into several levels to form a hierarchical tree (Fig. 2). Using AHP, each criterion is compared with every other criterion of the same level in their contribution to the goal in an 'm × m' pairwise comparison matrix (Fig. 3). The same applies for comparing the sublevel criteria within their own branch. The value in cell a_{ij} indicates the importance of the criterion listed in the left-hand side column with respect to the criterion on the top row on a nine-point numerical scale (Table 1). When $a_{ij} = k$, then $a_{ji} = 1/k$ must hold for consistency reasons. Subsequently, the weights are obtained: firstly by summing each column, secondly by dividing every cell by its column total and finally by taking the average of each row [40,51–53]. A consistency ratio (CR) is calculated to check for inconsistency in the decision maker's comparisons. The CR of a pairwise comparison matrix is the ratio of its consistency index (CI) (*i.e.* the maximum eigenvalue of the comparison matrix) to the corresponding random index. The CR should not exceed 0.10 for a matrix larger than '5 × 5'. Detailed calculations of the CR and CI can be found in references [52,53].

Using outranking methods, the criteria are ranked per hierarchical level. A weight w_j.assigned to each criterion depending on the rank order of the criterion using equation (3).

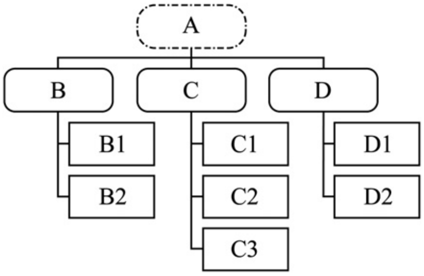

Fig. 2 – Hierarchical tree.

CE RE	C1	C2	C3
C1	1	a	1/b
C2	1/a	1	c
C3	b	1/c	1

Fig. 3 – Pairwise comparison matrix.

$$w_j = \frac{\frac{1}{k}}{\sum_{k=1}^{n} \frac{1}{k}} \tag{3}$$

where k is the priority level or ranking of criterion j ($k = 1$: most important criterion; $k = n$: least important criterion) [54].

The weights of the main level criteria sum to one hundred and sublevel criteria's weight sum to the respective weight of their main level criterion. For example in Fig. 2, the sum of the weights of the criteria B–D is one hundred. The weights of the sublevel criteria B1 and B2 sum to the weight of the main level criterion B. Here the rule for the number of criteria per sublevel becomes important (see *supra*, Section 2.1). Indeed, the relative share of a criterion belonging to a main criterion having lots of subcriteria is automatically lower than that of a criterion belonging to a main criterion having a similar weight but less subcriteria.

Fischhoff *et al.* [55] demonstrated that the resulting weights can be influenced by the MCDA method since participants generally do not have a clear preference. As every method has its own advantages and drawbacks, it is not possible to indicate one method as being more suitable than another [22,42]. Therefore, it is recommended to use more than one MCDA method to provide comparative information and enhance the efficacy and empirical validity of the results and to select the most appropriate tool for a given problem [19,22,25,37,45,56,57]. However, Løken [22] concludes that it is not possible to claim that one of the MCDA methods is generally more suitable than the others are. Bell *et al.* [58] argue that the most appropriate method depends on the set of assumptions that seems most valid for a given situation and person. In literature there is

Table 1 – Nine-point scale [50].

1	Both criteria contribute equally to the objective
3	Moderately higher contribution to the objective of row element (RE) as compared to column element (CE)
5	Higher contribution to the objective of RE as compared to CE
7	Much higher contribution to the objective of RE as compared to CE
9	Complete dominant contribution to the objective of RE compared to CE
2, 4, 6, 8	Intermediate levels

ample evidence of differences in results and recommendations between methods [59]. According to Jia & Fischer [60] the difference between methods becomes larger and more important as the number of alternatives and criteria increase. However, Hobbs & Horn [56] conclude that these disagreements or inconsistencies are inevitable and should be welcomed as an expression of the different suitability of a method for a particular situation and a decision maker.

MCDA methods take objective characteristics as well as the preferences of decision makers into account [61]. Since MCDA methods are subjective, it is thus possible to direct the outcome into a certain direction. This guidance is by no means unwanted since multi-criteria decision tools have been developed to assist the decision makers in efficiently and consistently formulating their true preferences [59,62]. The effectiveness of the approach is dependent on the interaction with the participants and the presentation of information in a way that facilitates active participation to enhance understanding, learning and discussion [23]. Also Hobbs *et al.* [63] conclude that careful tutoring and close collaboration between analysts and decision makers are more important than which method is adopted. Moreover, it is important to clearly communicate the goal and the impact of the weights to the experts. To gain more insight into the resulting weights, it is interesting to have some background information on the experts.

Some typical characteristics of biomass and its conversion to energy are its complexity, site-specificity, geographic dispersion, involvement of many diverse stakeholders, and influence on different factors [2,6,29,64,65]. These characteristics imply some specific drawbacks for using MCDA in the case of biomass applications. Due to the complexity and diversity of biomass it is difficult to define criteria such that stakeholders interpret them all in the same way. Important is the participatory development of a clear definition for every criterion with the different stakeholders or the explicit explanation to the stakeholders before starting the weighting procedure. Furthermore, the score should be carefully explained to the stakeholders. The process to come to an agreement for every criterion can be very time consuming. Therefore, it is interesting to develop a uniform list of criteria that can be used as a starting point for every biomass project. The advised set of criteria in this paper can be a first step to a needed uniform set of criteria for the primary screening of potential biomass conversion locations [18,19,45]. Despite the development of a uniform set of criteria, it is not possible to make a general clear-cut list that can be transferred without any adaptation to every region. Another prevalent drawback for biomass decision making is the large difference between the involved stakeholders, for example in professional knowledge, background, as well as educational level. Therefore, some stakeholders will be more confident in expressing the importance of indicators, while others will have difficulties with understanding criteria and/or methodologies. Researchers have to take this into account and find a balance among all participants [41]. The combination of the above elements specific for biomass makes it difficult to find an optimal balance between the method's complexity and sufficient coverage of all factors influencing biomass projects.

2.4. *Final score*

By summing the multiplication of the scores (step 2) with the weights (step 3) per criterion, a final score for every alternative is obtained. This method is based on the weighted sum method (WSM) [25], a simple and user-friendly approach to identify the most preferred alternative [22,50]. The higher the final score, the more interesting an option is. Another method to get a final ranking may be used as well. The resulting rank order merely gives an indication of the most interesting options. The advantage of using MCDA methods is that it makes the decision making process traceable and transparent. Based on a GIS visualization (see *infra*, Section 2.5) the decision maker can show why some decisions were made that are slightly differing from the final rank order obtained via our method. In the end it is the decision maker that makes the final decision. It is recommended that the neighboring areas are taken into account as well. On the one hand to check for serendipitous synergies, on the other hand to look for areas that are less attractive due to their low-score surrounding areas.

After obtaining the final scores, the decision maker can reflect on the results. Criteria can be deleted or added, however, in either case the process should be started again from the beginning bearing in mind the sensitivity of weight assignment methods for changes in criteria (see *supra*, Section 2.3).

2.5. *Spatial representation*

For biomass projects, the use of MCDA alone is not sufficient to take into account the geographic dispersion of biomass and the different geographical levels. A geographical information system (GIS, *i.e.* the software and hardware needed to display geographical data in a mapped format [27]) can be applied to the model's output for a better grasp on the geographical context. Furthermore, GIS allows for better data management on a spatial level [36]. There are many geographical levels (e.g. province, community, address) on which information can be found. The geographical level is dependent on the way results are represented: numerically or spatially. Information can be numerically ranked (*i.e.* solely based on the total score, the result of steps 1–4), which implies grouping on a common geographical level. However, some criteria can be valued on a more detailed level than others. For the use of MCDA one should always aggregate the information to the highest common level (*i.e.* least detailed) on which data is available. A coupling or integration with GIS is necessary, especially for biomass projects, to comprehensibly present data and/or results and visualize the data simultaneously on the detailed levels [21] (adding step 5). This more detailed representation allows for taking into account a more precise region during the micro-screening.

2.6. *Micro-screening*

The micro-screening follows directly after the macro screening and is not a step of the macro screening itself. The locations marked as ‘highly interesting’ in the macro screening should be investigated in more detail, described as a micro-screening. Relevant agencies, investors, partners,… are contacted personally and the needed information is gathered through questionnaires and interviews. In fact, a macro screening provides the information (and motivation) for investors and policy makers where to perform a micro-screening.

3. Case study

We have chosen to apply the methodology to the case of Limburg, a province in the northeastern part of Belgium. This area has a total surface of 2422 km^2 and is divided into forty-four communities with a rather high population density. It is a green province compared to other Flemish provinces, where renewable energy initiatives receive a lot of attention from different stakeholders (investors, policy, society, academics,…). Several projects are ongoing, such as a provincial project that strives towards a CO_2 neutral Limburg by 2020. We apply the above mentioned macro screening method to identify the most promising communities in the province to install a multi-dimensional biomass project.

3.1. *Criteria determination*

In the first step experts were identified to determine the useful criteria for regional, multi-dimensional biomass projects. In total ten experts were consulted, all with different professional backgrounds. A meeting was organized to stimulate the experts in expressing their points of view after which the most important criteria were deducted. As defined in Section 2.1, four main criteria were identified. Each criterion consists of a number of subcriteria (see Fig. 4). The subcriteria used to estimate the amount of biomass input are selected as such that they do not compete with food, feed or other high value applications. Generally spoken one can take into account residues from industry, agriculture, forests, communities and nature. The specific residues are dependent on climate and soil characteristics and hence differ for every region. However, since we score for example the residues from agriculture as the total amount of hectares dedicated to agriculture, this criterion can be used in every region (see *infra*, Section 3.2). Experts agreed that it was not interesting to break the criteria down for every type of agricultural crop since this would make the weight assignment too complex. The subcriteria for 'Society' are the most difficult to advise a uniform list for, since these are highly situation dependent. Moreover, it is not possible to recommend an aggregated level that allows for sufficient detail.

3.2. *Data gathering*

In the next step information was gathered for each of the criteria using desk research. The exact measure used for each of the criteria is given in Table 2. 'Input' contains the biomass potentials. Different types of potential exist: theoretical, technical, economic, sustainable, … [64]. In our study the theoretical potential (*i.e.* the overall maximum amount of biomass which can be considered theoretically available within fundamental bio-physical limits [6]) is used since the macro screening focuses on minimizing the time needed. It is however important to keep this difference in mind. In many situations the economic potential is of interest. In the micro-screening the restrictions needed to find the economic or even the sustainable potentials should be provided. In order to gather these restrictions, one has to perform questionnaires and/or interviews. Considering the large area that is under revision for interviewing, it is necessary to narrow the scope first. To that end the macro screening is a very useful tool. Note that for the sub criterion 'wood (forest)' for instance the

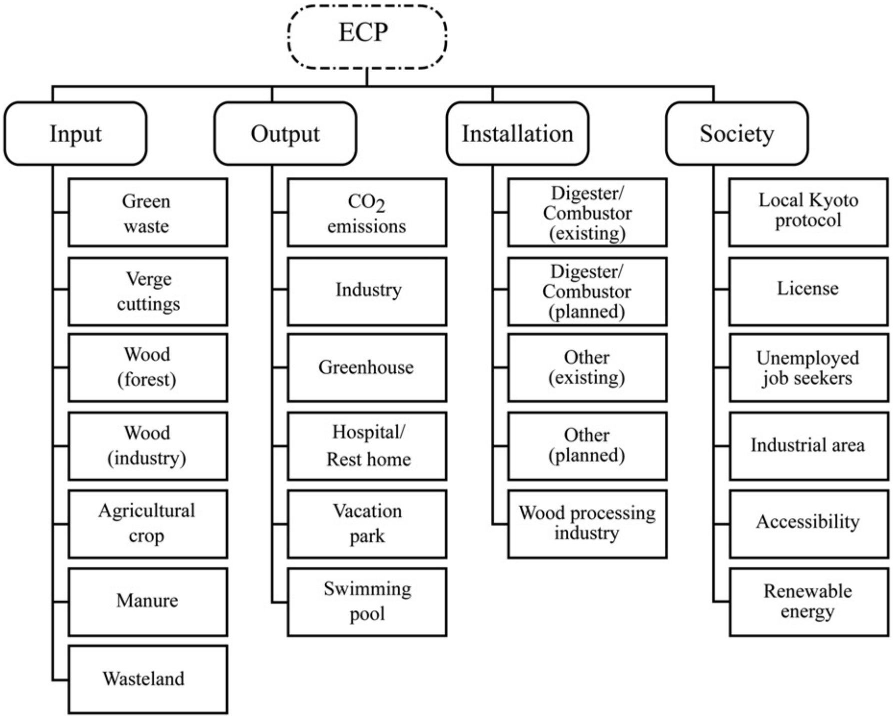

Fig. 4 – Selected criteria based on expert knowledge.

Table 2 – Criteria measures.

Input			
Green waste[a]	Vegetable, fruit and garden waste (ton)	Agricultural crops[h]	Total area dedicated to agricultural crops (ha)
Verge cuttings[b,c,d]	Verge cuttings (ton)	Manure[h,i]	Manure from pork, cattle and chicken (ton)
Wood (forest)[e,f]	Total area of forestry (ha)	Wasteland[h]	Total area of wasteland (ha)
Wood (industry)[g]	Total amount of carpentries (#)		
Output			
CO_2 emissions[j]	Total amount of CO_2 allowances (ton CO_2)	Hospitals/Resthomes[l,m]	Total amount of beds in hospitals and rest homes (#)
Industry[k]	Total amount of breweries, food industry, furniture industry, drying (#)	Vacation parks[n]	Total amount of cottages (#)
Greenhouses[h]	Total area dedicated to greenhouses (ha)	Swimming pools[o]	Total amount of indoor, heated outdoor and subtropical pools (#)
Installation			
Digester/combustor (existing)[p]	Installed power from digesters and combustors (kW)	Other (planned)[q]	Total amount of planned bio-oil, bio-steam, compost and torrefaction installations
Digester/combustor (planned)[p]	Planned power from digesters and combustors (kW)	Wood processing industry[g,k]	Total amount of carpentries (#)
Other (existing)[q]	Total amount of existing bio-oil, bio-steam, compost and torrefaction installations		
Society			
Local Kyoto protocol[r]	Community acknowledgment of the local Kyoto protocol (yes-no)	Industrial area[k]	Total area of free industrial area (ha)
License[p]	Total number of licenses granted for biomass-to-energy conversion installations (#)	Accessibility[b,d]	Total amount of motorways and waterways (km)
Unemployed job seekers[s]	Total amount of unemployed job seekers (#)	Renewable energy[p]	Total amount of installed power from renewable energy sources (sun, wind and biomass)

Sources.
a www.limburg.net
b FOD economie 'lengte van het wegennet'.
c CMK Uhasselt.
d NV De Scheepvaart.
e AGIV.
f www.bosgroepen.be
g www.handelsgids.be
h FOD economie 'landbouwenquête'.
i MIRA.
j www.lne.be
k POM limburg.
l website hospitals.
m www.derusthuizen.be
n www.toerismelimburg.be
o http://zwembad.injebuurt.be/injebuurt/city/Limburg
p VREG.
q website installation.
r Bond Beter Leefmilieu.
s VDAB.

total area of forestry is taken into account. Consequently, it may seem that we have taken wood into account that could be used for furniture, particleboard, *etc*. However, on a macro-level a proxy could just as well have been used to estimate the amount of wood residues. For example, we could have used 0.48–2.64 ton/ha/year of woody residues [66,67] of which a minimum of 45% should stay within the forest for ecological concerns [68]. However, mathematically no difference in the final score will be noticeable, since the final score is normalized and thus that level of detail is lost. Still, since the macro screening is traceable it can be interesting to integrate this proxy and go back to it afterwards.

3.3. *Weight assignment*

A new expert meeting with twenty five participants was organized to agree upon the importance of every criterion shown in Fig. 4. Within the experts, two different groups can be distinguished: (1) the project group consisting of project partners, (2) the sounding board composed of stakeholders who are currently active in related activities (see *supra*, Section 2.1). The first group was also used earlier in step 1 (see Section 3.1) to determine the relevant criteria. The same criteria were presented to all experts to assign weights, representing their opinions and preferences. Every expert received an equal weight because their viewpoint was considered equally important. There was no correction for outliers since there was no reason to consider the opinion of an expert as being wrong. From every expert some background information was gathered by asking supplementary questions at the end of the weight assignment. They were asked which country they are living in, what their field of expertise is, which sector they are working in, which function they have and which biomass type is most related to their activities. In Table 3 the total number of experts per background criterion is summarized. This information will be used to check whether an expert's background has an influence on the assigned weights.

In our work the weights are obtained using the AHP method. Table 4 summarizes the geometric mean of the weight per criterion, as recommended by Saaty [69]. To check the robustness of these weights, they are compared with the weights obtained by direct weighting and ranking. The rank correlations (kendall's tau) were calculated and are all positive and significant as shown in Table 5. This means that the rank order of the weights does not differ much between the methods.

To see whether the expert's background has an influence on the assigned weights, a Kruskal–Wallis test is performed. The results are summarized in Table 6. The type of biomass that is most related to the expert's activities has an influence on most weights. The Kruskal–Wallis test indicates a difference between the groups for four criteria out of twenty-eight or 14% of the criteria, which is a rather small percentage. It may be concluded that in our case study the background of the experts has a negligible influence. The expert meeting to assign weights to the criteria was mainly composed of different experts compared to the ones determining the criteria. During the second expert meeting some concern was expressed because some sounding board members did not completely agree with the criteria or their definition. It is therefore important to stimulate the experts to fully share their opinions while providing sufficient answers to their questions. Our results show that the group to which an expert belonged, had an influence on solely two criteria.

Table 3 – Total number of experts per background criterion.

Criterion	Sub criterion	#
Group	Project group	8
	Sounding board	17
Country	Belgium	20
	The Netherlands	5
Expertise[a]	Biological	5
	Chemical	3
	Economic	5
	Technological	9
Sector	Industry	4
	Environment/Nature	6
	Academic	10
	Government	5
Function	Public servant	6
	Docent	4
	Researcher	8
	Project manager	7
Biomass	Wood	6
	General	12
	No affinity	7

a missing data.

Table 4 – Geometric mean weight per criterion via AHP.

Criterion	AHP
Input	41,33%
Output	27,86%
Installation	17,11%
Society	13,70%
Green waste	10,98%
Verge cuttings	8,57%
Wood (forest)	6,21%
Wood (industry)	4,67%
Agricultural crop	4,14%
Manure	3,52%
Wasteland	3,25%
CO_2 emissions	2,93%
Industry	7,65%
Greenhouse	6,67%
Hospital/Rest home	4,11%
Vacation park	2,97%
Swimming pool	3,52%
Local Kyoto protocol	1,15%
License	1,48%
Unemployed job seekers	0.76%
Industrial area	3,42%
Accessibility	4,87%
Renewable energy	2,02%
Digester/Combustor (existing)	4,36%
Digester/Combustor (planned)	3,31%
Other (existing)	3,92%
Other (planned)	3,07%
Wood processing industry	2,44%

3.4. *Final score*

Combining the scores with the weights resulted in one final score for every community, seeing that all scores were allocated to this common geographic level. Now, the communities can be ranked and demonstrated visually (see Fig. 5). The darker the area, the more interesting communities are to plant a multi-dimensional biomass project. As mentioned in Section 2.4, the decision maker makes the final decision which can differ slightly from the final ranking. The macro screening

Table 5 – Kendall's tau rank correlation.

Kendall's tau_b	AHP	Direct	Ranking
AHP	1	0.949**	0.943**
Direct		1	0.960**
Ranking			1

** 0.01.

Table 6 – Summary of Kruskal–Wallis tests.

Background	AHP	
	#	%
Country	2	7
Group	3	11
Function	3	11
Biomass	4	14
Expertise	2	7
Sector	2	7
Total: 28 criteria		

gives an indication of the most interesting locations, but cannot indicate the most preferred one. Once a decision has been taken, the method helps to create a supportive policy framework.

3.5. *Spatial representation*

However, for site selection it is interesting to take the different geographic levels into account and combine them for an integrated representation of the results. Given that this is hard to achieve numerically, the weighted criteria should be presented using GIS (Fig. 6). GIS allows us to display the results using raster data with a cell size of 500 m × 500 m. This way, it is possible to determine the regions, even within communities, which are particularly suitable for biomass conversion facilities. For all subcriteria in the criteria ‘Input’ and ‘Society’ we have chosen to use the level of communities. Since heat cannot be transported over a large distance, it is valuable to use the exact location of all potential heat customers in the ‘Output’ criterion. The same applies for the ‘Installation’ criterion. Extending a current installation or combining multiple techniques can only be done at that particular location, so only the score of that location (cell) is elevated. Fig. 6 shows the added value of using MCDA in combination with GIS. The color scale consists of the weighted scores for the different criteria. The darker the color of a location, the higher the score and the more interesting that location will be for biomass conversion projects.

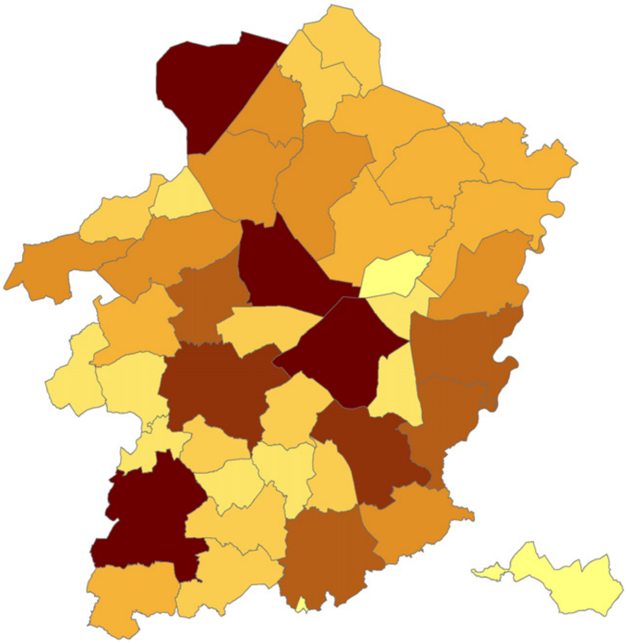

Fig. 5 – Spatial representation of final score per community.

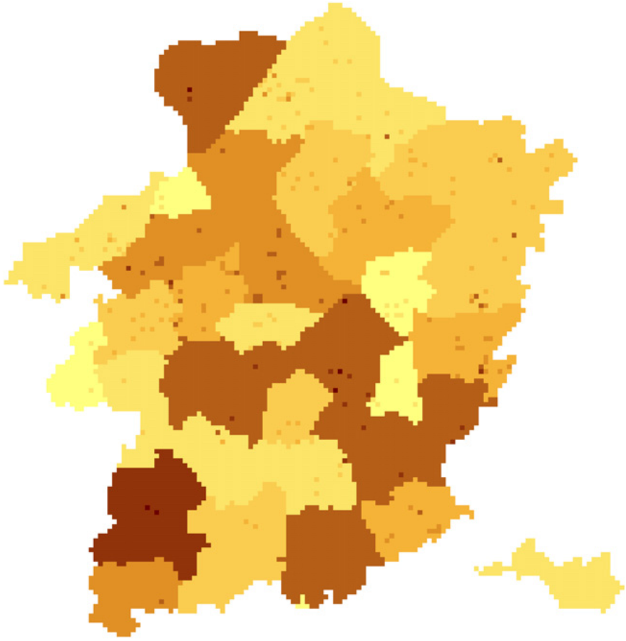

Fig. 6 – Spatial representation of weighted criteria.

4. Discussion and conclusion

A macro screening approach was developed and used to determine the most interesting locations for the Limburg province within a minimal time span. Starting with an expert meeting to determine the appropriate criteria is important to gain their support from the beginning. The weights, assigned via an AHP method, must also be determined by experts. By assigning weights, experts can guide the outcome into a certain direction. This guidance is valuable since it can generate insight into their different viewpoints. The final score is obtained by using a simple and traceable MAVT–based method. In the last phase GIS is used to arrive at a clear, visual representation of the different weighted criteria. GIS allows for an integration on different geographic levels to obtain a more detailed representation of the results. The macro screening only gives an indication of the potentially interesting locations and cannot select the best location among the alternatives. Therefore, it cannot stand alone as a decision tool and should be succeeded by a thorough investigation of the best-scoring locations. The macro screening approach is a supportive and motivational tool to utilize as input for the micro-screening to support and motivate partners, investors, policy makers,… that allows for studying the possibilities of building biomass conversion plants at specific locations. In a follow-up paper this micro-screening will be further elaborated on. It will take into account the economic biomass potential within a chosen region. Stakeholder interviews will be done to identify the interest to participate in the project. Also the transport situation and economic parameters will be integrated. Our case study has shown that it was possible to drastically reduce the potential locations to place a multi-dimensional biomass project to the most interesting ones using a macro screening. It can therefore be concluded that our method provides a fast and efficient way to explore the market for biomass valorization site selection. Moreover the method is generic, so it can be applied to other domains, such as other renewable energy projects (sun, wind,…) or for example site selection for schools, nursing homes, hospitals or industry. Furthermore, it would be interesting to apply the methodology in another region with its own characteristics such as other specific biomass characteristics, legal environment and economic situation.

In the following some recommendations for further research are given. Firstly some criteria are rather ambiguous and can be seen as benefit criteria (synergy) or as cost criteria (competition). This distinction has an influence on the equations to use in the normalization step. In our study 'Installation' is an example of such a criterion. The criterion and its subcriteria are considered as benefit criteria in our model since the major part of the experts indicated them as such. However, Table 7 shows that the opinion of the experts were not that unanimous for all criteria. An additional expert discussion could provide some clarity.

Secondly our case study indicated that the differences in attributed weight between the project group and the sounding board were only significant in 11% of the criteria. During the second meeting some concern was expressed about the selected criteria, but the fact that the criteria were determined by other experts seemed comforting. Further research should be performed to prove whether this comforting feeling is really a result of the knowledge that the criteria were determined by experts or that it is sufficient to determine the criteria ourselves and to provide the experts with sufficient information about the choice and definition of criteria. One can ask oneself what the actual influence of weighing is. In our case study the weights only have a limited impact on the top ten ranked communities. If our goal was to solely indicate those communities that have the most potential, the same weight (or even no weight) could have been assigned to all criteria. Nevertheless, the weights give an insight in the importance experts attach to criteria and thus indicate how experts would make their choice if no macro screening was used. The weights do have an impact on the middle ranked communities. Hence, one of the advantages of using GIS is that neighboring communities can be taken into account when making the final decision. Since neighboring communities may be middle ranked, it is very interesting to assign weights when using GIS. Note that in other studies the weights can have an influence on all alternatives.

Table 7 – Synergy versus competition.

Criterion	Synergy	Competition
Digester/Combustor (existing)[a]	14	9
Digester/Combustor (planned)[a]	13	10
Other (existing)[a]	16	6
Other (planned)[a]	18	4
Wood processing industry[a]	19	2

a missing data.

Thirdly, in our case study an expert's background does not have an influence on the assigned weights. Further research should indicate whether there are other variables that do have an impact on the resulting weights.

Finally, in some cases it can be desirable to exclude a location when the score on one criterion is unacceptably low or even nonexistent. In other words, the low-score for that criterion cannot be compensated by a high score for another criterion.

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